



U.S. Department  
of Transportation  
**Federal Aviation  
Administration**

# Advisory Circular

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**Subject:** FUEL TANK IGNITION SOURCE  
PREVENTION GUIDELINES

**Date:** 4/18/01

**Initiated By:** ANM-112

**AC No:** 25.981-1B

**Change:**

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1. PURPOSE. This advisory circular provides guidance for demonstrating compliance with the certification requirements for prevention of ignition sources within the fuel tanks of transport category airplanes. This guidance is applicable to transport category airplanes for which a new, amended, or supplemental type certificate is requested.

2. APPLICABILITY.

a. The guidance provided in this document is directed to airplane manufacturers, modifiers, foreign regulatory authorities, and Federal Aviation Administration transport airplane type certification engineers, and their designees.

b. This material is neither mandatory nor regulatory in nature and does not constitute a regulation. It describes acceptable means, but not the only means, for demonstrating compliance with the applicable regulations. The Federal Aviation Administration will consider other methods of demonstrating compliance that an applicant may elect to present. Terms such as "shall" and "must" are used only in the sense of ensuring applicability of this particular method of compliance when the acceptable method of compliance described in this document is used. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations.

c. This material does not change, create any additional, authorize changes in, or permit deviations from, regulatory requirements.

3. CANCELLATION. Advisory Circular 25.981-1A, Guidelines for Substantiating Compliance with the Fuel Tank Temperature Requirements, dated January 20, 1971, is cancelled.

4. RELATED DOCUMENTS. The following related documents are provided for information purposes and are not necessarily directly referenced in this AC.

a. Federal Aviation Regulations. Sections that prescribe requirements for the design, substantiation, and certification relating to prevention of ignition sources within the fuel tanks of transport category airplanes include:

- § 21.50 Instructions for continued airworthiness and manufacturer's maintenance manuals having airworthiness limitations sections.
- § 25.729(f) Protection of equipment in wheel wells.
- § 25.863 Flammable fluid fire protection.
- § 25.901 Installation (Powerplant)
- § 25.954 Fuel system lightning protection.
- § 25.973 Fuel tank filler connection.
- § 25.981 Fuel tank ignition prevention.
- § 25.1301 Function and installation (Equipment)
- § 25.1309 Equipment, systems, and installations.
- § 25.1316 System lightning protection.
- § 25.1353 Electrical equipment and installations.
- § 25.1529 Instructions for continued airworthiness
- Appendix H Instructions for continued airworthiness

b. FAA Directives.

Notice N 8110.71 Guidance for the Certification of Aircraft Operating in High Intensity Radiated Field (HIRF) Environments.

c. Advisory Circulars (AC). You can obtain any of the advisory circulars listed below either electronically from the internet at <http://www.faa.gov/avr/air/acs/achome.htm> or from the U.S. Department of Transportation, Subsequent Distribution Office, SVC-121.23, Ardmore East Business Center, 3341 Q 75<sup>th</sup> Avenue, Landover, MD 20785.

AC 25-8	Auxiliary Fuel System Installations
AC 20-53A	Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due to Lightning, (see also Users Manual)
AC 20-136	Protection of Aircraft Electrical/Electronic Systems against the Indirect Effects of Lightning
AC 25-16	Electrical Fault and Fire Prevention and Protection
AC 25-19	Certification Maintenance Requirements
AC 25.981-2	Fuel Tank Flammability Minimization

d. Society of Automotive Engineers (SAE) Documents. You can obtain the following documents from the Society of Automotive Engineers, Inc., 400 Commonwealth Drive, Warrendale, Pennsylvania, 15096.

(1) AIR5128, Electrical Bonding of Aircraft Fuel System Plumbing Systems, January 1997.

(2) APR4754, Aerospace Recommended Practice, Certification Considerations For Highly Integrated or Complex Aircraft Systems.

(3) ARP 4761, Aerospace Recommended Practice, Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment.

(4) ARP4404, Aerospace Recommended Practice, Aircraft Electrical Systems (guidance document for design of aerospace vehicle electrical systems).

e. Military Specifications.

(1) MIL-B-5087B, System Electrical Bonding.

(2) AS50881, Aerospace Vehicle Wiring (procurement document used to specify aerospace wiring, replaces MIL-W-5088).

(3) MIL-E-5272A - Environmental Testing of Aeronautical & Associated Equipment (Explosion Proof Equipment Qualification Tests).

(4) MIL-STD-810E, Method 511.3, Explosive Atmosphere, dated September 1, 1993.

f. Other.

(1) RTCA Document DO-160D, Environmental Conditions and Test Procedures for Airborne Equipment.

(2) International Electrotechnical Commission (IEC), IEC60079-11, Electrical Apparatus for Explosive Gas Atmospheres.

(3) Underwriters Laboratories Inc., UL 913, Intrinsically Safe Apparatus and Associated Apparatus for use in Class I, II, III, Division 1, Hazardous (Classified) Locations.

(4) FAA Transport Airplane Directorate Designee Newsletter, Edition 15, February 1993. Article, Electrical Wiring used in Commercial Transport Airplanes.

(5) FAA Regulatory Support Division (AFS-500 or -600), Oklahoma City, Project 414-76a (01603), Explosion Potential for Electrical Items in Fuel Tanks.

(6) FAA Document DOT/FAA/AR-98/26, Review of the Flammability Hazard of Jet A Fuel Vapor in Civil Transport Aircraft Fuel Tanks, June 1998.

(7) Kuchta, Joseph M., Summary of Ignition Properties of Jet Fuels and Other Aircraft Combustible Fluids, Air Force Aero Propulsion Laboratory Technical Report AFAPL-TR-75-70, U.S. Bureau of Mines PMSRC, 1975.

5. DEFINITIONS.

- a. Auto-ignition temperature. The minimum temperature at which an optimized flammable vapor and air mixture will spontaneously ignite.
- b. Auxiliary Tanks. Fuel tanks installed which make additional fuel available for increasing the flight range of that airplane. The term “auxiliary” means that the tank is secondary to the airplane’s main fuel tanks; i.e., the functions of the main tanks are immediately available and operate without immediate supervision by the flightcrew in the event of failure of inadvertent depletion of fuel in an auxiliary tank. Auxiliary tanks are usually intended to be emptied of usable fuel during flight and have been installed in various locations including center wing structure, horizontal stabilizers, wings and cargo compartments.
- c. Critical Design Configuration Control Limitations. Limitations that define those parameters of the design that must be maintained to ensure that ignition sources will not develop within the fuel tank.
- d. Electrical Arc or Spark. The transfer of electrons across a gap.
- e. Explosion Proof. Components designed and constructed so they will not ignite flammable vapors or liquids surrounding the component, under any normal operating and anticipated failure condition.
- f. Flammable. Flammable, with respect to a fluid or gas, means susceptible to igniting readily or to exploding (14 CFR Part 1, Definitions). Further information on flammable fluids used in airplanes may be found in the documents identified in paragraph 4f of this AC.
- g. Flash point. The flash point of a flammable fluid is defined as the lowest temperature at which the application of a flame to a heated sample causes the vapor to ignite momentarily, or “flash.” The test standard for jet fuel is defined in the fuel specification.
- h. Friction Spark. A heat source in the form of a spark that is created by mechanical contact, such as debris contacting a rotating fuel pump impeller.
- i. Hot Short. Electrical energy introduced into equipment or systems as a result of unintended contact with a power source, such as bent pins in a connector or damaged insulation on adjacent wires.
- j. Ignition source. A source of sufficient energy to initiate combustion of the fluid. Surfaces that can exceed the auto-ignition temperature of the fluid under consideration are

considered to be an ignition source. Electrical arcs and friction sparks are also common ignition sources.

k. Installation Appraisal. A qualitative appraisal of the integrity and safety of the installation.

l. Intrinsically Safe. Any instrument, equipment, or wiring that is incapable of releasing sufficient electrical or thermal energy under normal operating or anticipated failure conditions to cause ignition of a specific hazardous atmospheric mixture in the most easily ignited concentration.

m. Latent Failure. A failure whose presence may not be readily apparent to the flightcrew or maintenance personnel. A significant latent failure is one that would, in combination with one or more specific failures or events, result in a hazardous or catastrophic failure condition.

n. Maximum allowable surface temperatures. There is a general industry/FAA practice that a maximum allowable surface temperature that provides a safe margin under all normal or failure conditions is at least 50°F below the lowest expected auto-ignition temperature of the approved fuels. The auto-ignition temperature of fuels will vary because of a variety of factors (ambient pressure, dwell time, fuel type, etc.), but the value generally accepted without further substantiation for kerosene type fuels, such as Jet A, under static sea level conditions, is 450°F. This results in a maximum surface temperature of approximately 400°F for an affected component or surface.

o. Qualitative. Those analytical processes that assess system and airplane safety in an objective, non-numerical manner.

p. Quantitative. Those analytical processes that apply mathematical methods to assess system and airplane safety.

q. Transient Suppression Device (TSD): A device that limits electrical signals that enter fuel tanks on fuel tank gauging system wires to intrinsically safe levels.

## 6. BACKGROUND.

### a. Regulatory History.

(1) The regulatory standards of part 25 require that ignition sources not be present or develop in the fuel tanks of transport airplanes. Amendment 25-11, effective May 5, 1967, introduced § 25.981, Fuel tank temperature. This requirement was prompted by a need for protection of airplane fuel tanks from possible ignition sources because of advances in electrical system sealing. These advances made it possible to place electrical system components, such as pumps and fuel gauging elements, as well as the wiring to these components, in immersed locations within fuel tanks. Additionally, fuel tank walls were subject to local "hot spots" by the

proximity of airplane equipment and compressor bleed air ducts that carry air at high temperatures.

(2) The need for a regulation was further demonstrated by the possibility that the surface temperature of the fuel tank internal wall, or the fuel system components within the fuel tank, could exceed the auto-ignition temperature. Section 25.981, as originally adopted, focused on preventing ignition of fuel vapors in the fuel tanks from hot surfaces. In addition, it required that the applicant determine the highest temperature allowable in fuel tanks that provided a safe margin below the lowest expected auto-ignition temperature of the fuel approved for use in the fuel tanks. In addition, this regulation established a requirement that no temperature at any place inside any fuel tank where fuel ignition is possible may then exceed that maximum allowable temperature.

(3) Other sections of part 25 require that ignition from lightning be prevented (§ 25.954), as well as ignition from failures in the fuel system (§ 25.901). Applicants have been required by § 25.901 to complete a safety assessment of the fuel system and show that “no single failure or malfunction or probable combination of failures will jeopardize the safe operation of the airplane....” However, service history has shown that ignition sources have developed in airplane fuel tanks due to unforeseen failure modes or factors that were not considered at the time of original certification of the airplane, including arcs, sparks, or hot surfaces within the fuel tanks.

b. Advisory Circular 25.981-1A, Guidelines for Substantiating Compliance with the Fuel Tank Temperature Requirements, published in 1972, provided guidance that included failure modes that to be considered when determining compliance with the fuel tank temperature requirements defined in § 25.981. This regulation focused on preventing ignition of fuel vapors in the fuel tanks from hot surfaces. The AC also recommended a minimum 50°F temperature margin below the lowest auto-ignition temperature of the approved fuels.

c. Amendment 25-102, issued on April 18, 2001, renamed § 25.981 as Fuel Tank Ignition Prevention, and added new requirements to address causes of ignition sources within fuel tanks and minimization of the development of flammable vapors in the fuel tanks or mitigation of the effects of an ignition of vapors in the tanks. The new ignition source prevention standard requires a safety assessment of the fuel tank system that includes:

- consideration of single failures,
- probable combinations of failures,
- development of long-term instructions for continued airworthiness, and
- maintainability of the airplane fuel tank system

d. Special Federal Aviation Regulations (SFAR) No. 88, promulgated by Amendment No. 21-78, also issued on April 18, 2001, requires a one-time reassessment of the fuel tank systems of many in service transport airplanes per the ignition source prevention requirements of § 25.901 and the amended § 25.981.

e. The purpose of this AC is to provide guidelines that address precluding possible sources of ignition in airplane fuel tanks. Analytical evaluation of the fuel tank system, including consideration of lessons learned from the transport airplane service history, provide insight into design features that should be carefully considered when determining compliance with the regulations that are intended to preclude ignition sources within fuel tanks. Prior to conducting a fuel system safety assessment, each applicant should assemble and review relevant lessons learned from their previous products, their suppliers, and any other available sources, to assist in identifying any unforeseen failures, wear, or other conditions that could result in an ignition source. Sources of information include airplane service records, flight logs, inspection records, and component supplier service and sales records. Guidance relating to the flammability requirements adopted in amended § 25.981 is provided separately in AC 25.981-2, Fuel Tank Flammability Minimization.

f. Safety assessments of previously certificated fuel systems may require additional considerations. For retroactive safety assessments, component sales records may assist in identifying if component failures and replacement are occurring. In addition, in some cases changes to components have been introduced following original type design certification without consideration of the possible effects of the changes on the system's compliance with the requirements to preclude ignition sources. For example, certain rotating components and static parts within fuel pumps have been changed to steel to improve pump life, which defeated the original fail-safe features of the pumps because steel components introduce the possibility of sparks being generated when contacted by adjacent components or debris within the pump. Therefore, results of reviewing this service history information, and a review of any changes to components from the original type design, should be documented as part of the safety analysis of the fuel tank system.

g. The following list summarizes fuel tank system design features, malfunctions, failures, and maintenance related actions that have been identified through service experience as resulting in a degradation of the safety features of airplane fuel tank systems. They may assist in evaluating possible failure modes during evaluation of the fuel tank installation.

Pumps:

- Ingestion of pump inlet components (e.g. inducer, fasteners) into the pump impeller releasing debris into the fuel tank.
- Pump inlet case degradation, allowing the pump inlet check valve to contact the impeller.
- Failure of one phase of the stator winding during operation of the fuel pump motor together with subsequent failure of a second phase of the motor windings, resulting in arcing through the fuel pump housing.

- Arcing due to the exposure of electrical connections within the pump housing that have been designed with inadequate clearance to the pump cover.
- Omission of cooling port tubes between the pump assembly and the pump motor assembly during pump overhaul.
- Extended dry running of fuel pumps in empty fuel tanks, which was contrary to the manufacturer's recommended procedures.
- Use of steel impellers that may produce sparks if debris enters the pump.
- Debris lodged inside pumps.
- Pump power supply connectors have corroded resulting in fuel leakage and electrical arcing.
- Electrical connections within the pump housing have been designed with inadequate clearance or insulation from the metallic pump housing resulting in arcing.
- Thermal switches aging over time resulting in a higher trip temperature.
- Flame arrestors falling out of their respective mounting.
- Internal wires coming in contact with the pump rotating group, energizing the rotor and arcing at the impeller/adaptor interface.
- Poor bonding across component interfaces.
- Insufficient ground fault current protection capability.
- Poor bonding of components to structure.
- Loads from the airplane fuel feed plumbing were transferred into the pump housing resulting in failure of the housing mounts and subsequent failure of the pump case, which defeated the explosion proof capabilities of the pump.
- Premature failure of fuel pump thrust bearings allowing steel rotating parts to contact the steel pump side plate.

#### Wiring to fuel pumps:

- Wear of Teflon sleeving and wiring insulation on wires in metallic conduits located inside fuel tanks, allowing arcing from wire through the conduits into fuel tank ullages.
- Damage to insulation on wiring routed adjacent to the fuel tank exterior surfaces that resulted in arcing to the metallic fuel tank surface.

#### Fuel Pump Connectors:

- Electrical arcing at connections within electrical connectors due to bent pins or corrosion.
- Fuel leakage and subsequent fuel fire outside of the fuel tank caused by corrosion of electrical connectors inside the pump motor which lead to electrical arcing through the connector housing (connector was located outside the fuel tank).
- Selection of improper insulating materials in connector design resulting in degrading of the material because of contact with fuel that is used to cool and lubricate the pump motor.

#### Fuel Quantity Indicating System (FQIS) Wiring:

- Degradation of wire insulation (cracking) and corrosion (copper or silver sulfur deposits) at electrical connectors.
- Conductive or semi-conductive corrosion deposits (sulfide deposits) at electrical connectors inside fuel tanks.
- Unshielded FQIS wires routed in wire bundles together with high voltage wires, creating the possibility of short circuit failures or induced current on the FQIS wires in excess of intrinsically safe levels.

#### FQIS Probes:

- Conductive or semi-conductive corrosion (copper or silver sulfur deposits) causing reduced breakdown voltage in FQIS wiring.
- Damage to FQIS wire insulation resulting in reduced breakdown voltage as a result of wire clamping features at electrical connections on fuel quantity probes.
- Contamination in the fuel tanks creating an arc path for low levels of electrical energy between FQIS probe walls (steel wool, lock wire, nuts, rivets, bolts, and mechanical impact damage to probes).

#### Bonding Straps:

- Corrosion of bonding strap wires resulting in failure of wires.
- Inappropriately attached connections (loose or improperly grounded attachment points).
- Static bonds on fuel system plumbing connections inside the fuel tank worn due to mechanical wear of the plumbing from wing movement, and corrosion.
- Corrosion of bonding surfaces near fuel tank access panels that could diminish the effectiveness of bonding features.
- Aging of self-bonding fuel system plumbing connections resulting in higher resistance bonding.

#### Pneumatic System Failures:

- Leakage of air from ducting located near fuel tanks due to duct failure resulting in undetected heating of tank surfaces above the auto-ignition temperature.

#### Electrostatic Charge:

- Use of non-conductive reticulated polyurethane foam that holds electrostatic charge build up.
- Spraying of fuel into fuel tanks through inappropriately designed refueling nozzles
- Spraying of fuel into fuel tanks from fuel pump motor cooling flow return ports that spray fuel into the tank.

## 7. FUEL TANK IGNITION SOURCES.

a. There are four primary phenomena that can result in ignition of fuel vapors from within airplane fuel tanks:

- electrical arcs,
- filament heating
- friction sparks, and
- hot surface ignition or auto-ignition

(1) The conditions required to ignite fuel vapors from these ignition sources vary with pressures and temperatures within the fuel tank and can be affected by sloshing or spraying of fuel in the tank. Due to the difficulty in predicting fuel tank flammability and eliminating flammable vapors from the fuel tank, the regulatory authorities have always assumed that a flammable fuel air mixture may exist in airplane fuel tanks and have required that no ignition sources be present.

(2) Any components located in or adjacent to a fuel tank must be qualified to meet standards that assure, during both normal and anticipated failure conditions, that ignition of flammable fluid vapors will not occur. This is typically accomplished by a combination of component testing and analysis. Testing of components to meet explosion-proof requirements is carried out for various single failures, and combinations of failures, to show that arcing, sparking, auto-ignition, or flame propagation from the component will not occur. Testing of components has been accomplished using several military standards and component qualification tests. For example, military standard MIL-STD-810, Method 511, Procedure I and II, defines one method that has been accepted for demonstrating that a component is explosion proof. Section 9 of RTCA Document DO 160D has also been accepted for demonstrating that electronic equipment is explosion proof.

b. Electrical Arcs. Laboratory testing has shown that the minimum spark ignition energy required to ignite hydrocarbon fuel vapor is 200 microjoules. For electronic systems that introduce electrical energy into fuel tanks, such as fuel quantity indicating systems, the energy introduced into any fuel tank by a fully operational system should be limited to a value that assures the 200 microjoule limit is not exceeded during both normal and failure conditions with an appropriate safety margin. Electrical transients with the potential to create sparks in the fuel tank should be limited to less than 200 microjoules. (Electrical transient amplitudes less than 40 volts may be considered less than the potential required to create sparks.) In addition, to ensure that the design has adequate reliability and acceptable maintenance intervals, a factor of safety should be applied to this value when establishing a design limit. For example, a maximum of 20 microjoules is considered intrinsically safe for fuel quantity indicating systems.

c. Filament Heating Energy Limit. Analyses and testing indicate a small piece of wire from steel wool can ignite jet fuel when a current of 30 to 40 milliamperes root-mean-square (RMS) is applied to the wire. Therefore, electrical power with the potential to create a filament heating ignition source in the fuel tank should be limited to less than 30 milliamperes RMS. In

addition, to ensure that the design has adequate reliability and acceptable maintenance intervals, a factor of safety should be applied to this value when establishing a design limit.

d. Friction Sparks. Service experience has shown that pump inlet check valves, inducers, nuts, bolts, rivets, fasteners, sealant, lockwire, etc. have been inducted into fuel pumps and contacted the impeller. This condition could result in creation of friction sparks and should be an assumed failure condition when conducting the system safety assessment.

e. Hot Surface Ignition.

(1) Flammable Fluid Properties. Fuels approved for use on transport category airplanes have differing flammability characteristics. The autoignition temperature of JP-4, as determined by ASTM Test Method D286, is approximately 468°F at one atmosphere of pressure. By this method of testing, under the same atmospheric conditions the autoignition temperature of JET A (kerosene) is approximately 450°F, and of gasoline, approximately 800°F. The autoignition temperature of these fuels varies inversely with the ambient pressure. In view of this, factors affecting the pressure in the fuel tank should be taken into consideration when determining compliance with § 25.981.

(2) Maximum Surface Temperature. Guidance provided in AC 25-8, Auxiliary Fuel System Installations, defines surfaces that come within 50 degrees of the auto-ignition temperature of the fuel air mixture for the fluid as ignition sources. The FAA has approved installations, which experience surface temperatures in excess of 400°F. Manufacturers have substantiated that the conditions (ambient pressure, dwell time, fuel type, etc.) within fuel tanks are such that a higher value may be used. For example, a maximum allowable fuel tank surface temperature of 400°F, with a transient excursion up to 450°F for a maximum of two minutes, has been approved. The excursion above 400°F occurs only during failure conditions such as failure of the engine pneumatic system to regulate temperature, or duct rupture. Approval of these elevated temperatures has been based on compensating design features, such as an over-temperature shutoff of the pneumatic system so that the temperature cannot exceed the accepted 450°F value.

## 8. DESIGN CONSIDERATIONS.

a. Accepted Design Practices for Minimizing Ignition Sources. The number of components and systems inside airplane fuel tanks whose failure could result in an ignition source within the fuel tank should be minimized. For example:

(1) Fiber Optics. Wiring entering the tank for such purposes as temperature monitoring and fuel quantity indication should be minimized. Use of new technology, such as fiber optics, may provide a means of reducing or eliminating electrical powered components from inside the fuel tanks.

(2) Routing Of Pump Power Supply. If practical, fuel pumps should be located such that electrical power for the pumps is routed outside the fuel tanks in such a manner that failures in the electrical power supply cannot create a hot spot inside the tank or arc into the fuel tank.

**NOTE:** Structural considerations and fuel-feed system performance may make it impractical to locate the fuel pumps such that all wiring is routed outside the fuel tank.

(3) Pump Inlet. Another design practice that should be considered is locating fuel pumps such that the pump inlet remains covered with fuel throughout the airplane operating envelope.

(a) Main Feed Tanks. Installation of baffles in tank structure and use of collector tanks that are continually filled with fuel using ejector pumps are methods that have proven successful at keeping the pump inlets and pump housings submerged in fuel.

(b) Auxiliary Tanks. For auxiliary tanks that utilize motor driven fuel pumps and the tank is routinely emptied, accepted design practices include shutting off the motor driven pumps prior to uncovering the fuel pump inlet and installation of a flame arrestor in the scavenge pump inlet line, or scavenging the remaining fuel with ejector pumps. These methods should be effective under pitch and roll attitudes, and negative G conditions, anticipated to occur in service, but not when the main fuel tank quantity is depleted during fuel exhaustion conditions.

(4) Wiring.

(a) Intrinsically Safe. All wiring that is intended to conduct intrinsically safe levels (see paragraph 7b) of power into equipment located in the fuel tanks should incorporate protective features such as:

1 Separation of the fuel tank wires from higher energy carrying wires and shielding of the fuel tank wires; or

2 Installation of transient suppression devices, to preclude unwanted electrical energy from entering the tank.

These features should be provided unless it can be shown that an ignition source could not develop assuming the existence of contamination, corrosion, damage to probes, or other latent failures, including maintenance errors.

(b) Higher Energy Wiring.

1 Wiring should not be routed through metallic conduit or adjacent to fuel tank surfaces such that damage, inappropriate maintenance, or other failure/wear conditions could result in arcing to the conduit or metallic tank surface and development of an ignition source in the fuel tank. If metallic or other conductive conduit materials are used, the single failure of electrical arcing of the wiring to the conduit, adjacent tank surfaces, or structure should

be assumed to occur. In addition, circuit protective features or other features should be incorporated to preclude development of an ignition source in the fuel tank. Methods that may be used to address this foreseeable failure condition include the use of circuit protective features such as dual conduits, thick wall conduit, and/or fast-acting ground fault interrupter (GFI) circuit breakers.

2 Where electric wires are routed through conduits installed in a fuel tank, high surface temperatures or arcing through the conduit wall can be created by short circuits. All wiring conducting power (e.g. fuel pump power supply, fuel level sensor, etc.) into or through a fuel tank should be evaluated assuming arcing to adjacent surfaces such as metallic conduits or wing surfaces, unless fail-safe protective features are provided. A critical electrical wiring condition might be one in which the insulation is worn, cracked, broken, or of low dielectric strength, allowing intermittent or constant arcing to occur without consuming enough power to cause the circuit protection device to open. Inspection of wiring from in-service airplanes has shown that greater than expected wear may occur on sleeving and wiring insulation due to movement of the wire within the conduit. Roughness of the conduit material and variations in vibrations levels for each installation may significantly increase wear. In addition, inspections have shown that protective sleeving has been missing, improperly installed, or the wrong sleeving material used, resulting in damage to the insulation. The design should be tolerant to these types of foreseeable failure or maintenance errors.

(c) Circuit Breakers. Service experience has indicated that circuit breakers installed in the fuel pump circuits have not been shown to preclude arcing of electrical wiring through metallic barriers such as conduit or the tank wall into the fuel tank on some airplane designs. Evidence suggests that arcing from the wiring to metallic surfaces may not result in a hard short, which would trip the circuit breaker and may result in intermittent low level arcing that gradually arcs through the metallic barrier into the fuel tank. The design and routing of electrical wiring should be carefully evaluated to assure the design is, in fact, fail-safe.

(d) Use of Metallic Conduit. Advisory Circular 25-8 addresses the use of metallic conduit as an acceptable means for routing of electrical power within airplane fuel tanks. As indicated by service experience, these past practices would not meet the fail-safe requirements of § 25.981 unless additional fail-safe features were incorporated. Therefore, the guidance in AC 25-8 will be revised.

(e) Use of Non Metallic Conduit. If nonmetallic conduit is used, compatibility with fuel should be demonstrated. Aging due to heat, corrosion at the connecting fittings, and resistance to heat damage from internal shorts of wires routed within the conduit, should be evaluated.

b. Spark Energy Limit Margins. The electrical energy that enters a fuel tank is considered intrinsically safe if it is limited to less than the spark energy and filament heating energy limits previously provided. These values should not be exceeded under the single and multiple failure conditions as defined in the regulation. This may result in the need for the actual limits used for a design to include a factor of safety applied to each of these limits. The factor of safety provides

additional margin to ensure that when failures and malfunctions are considered, the design has adequate reliability and ensures continued safe operation between normal inspections or overhauls. The design limit used by the applicant for the design with no failures or malfunctions present, and the design limit used for the design with consideration for failures or malfunctions, should be stated in the compliance documentation.

## 9. SAFETY ANALYSIS.

a. Ignition Source Failure Analysis. Compliance with § 25.981 and SFAR No. 88 require each applicant to develop a failure analysis for the fuel tank installation to substantiate that ignition sources will not be present in the fuel tanks. The requirements of this section are in addition to the more general propulsion failure analyses requirements of §§ 25.901 and 25.1309 that have been applied to propulsion installations.

(1) Section 25.981(a)(3) defines three failure scenarios that must be addressed in order to show compliance with the rule:

- Each single failure, regardless of the probability of occurrence of the failure, must not cause an ignition source.
- Each single failure, regardless of the probability of occurrence, in combination with any latent failure condition not shown to be at least extremely remote (i.e., not shown to be extremely remote or extremely improbable), must not cause an ignition source.
- All combinations of failures not shown to be extremely improbable must not cause an ignition source.

(2) Compliance with § 25.981 (Amdt. 25-102) requires analysis of the airplane fuel tank system using analytical methods and documentation currently used by the aviation industry in demonstrating compliance with §§ 25.901 and 25.1309 with consideration of unique requirements included in the amendment.

(3) Advisory Circular 25.1309, System Design and Analysis, describes methods for completing system safety assessments (SSA). An assessment may range from a simple report that offers descriptive details associated with a failure condition, interprets test results, compares two similar systems, or offers other qualitative information, to a detailed failure analysis that may include estimated numerical probabilities. The depth and scope of an acceptable SSA depend upon:

- the complexity and criticality of the functions performed by the system under consideration,
- the severity of related failure conditions,
- the uniqueness of the design and extent of relevant service experience,
- the number and complexity of the identified causal failure scenarios, and

- the detectability of contributing failures.

**NOTE:** Sections 25.981 and 25.901 are intended to address system failures that may result in the presence of an ignition source in the fuel tanks. These regulations are not intended to address failures or conditions that could lead to ignition of fuel vapors from such sources as:

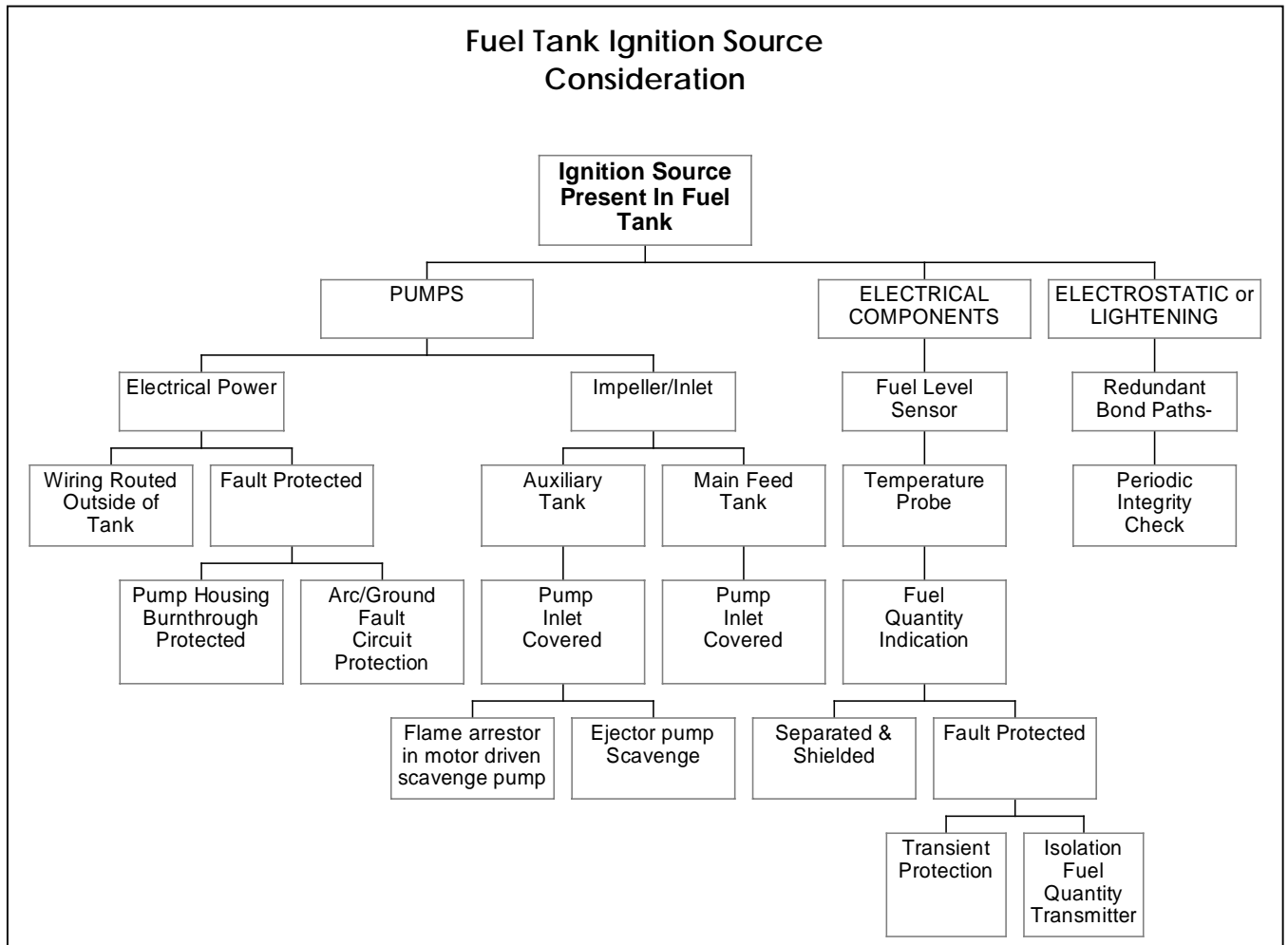
- uncontained engine debris,
- external engine fires following engine separation or failure,
- damage resulting from explosive materials, such as bombs,
- post crash fire heating of tank surfaces, or
- propagation of fire through the airplane vent system into the fuel tanks.

These hazards are addressed by other regulations.

b. Qualitative Safety Assessment.

(1) Typical airplane fuel tank systems have a limited number of possible ignition sources. Figure 1 shows causes of ignition sources and methods that may be used to meet the fail-safe requirements. The level of analysis required to show that ignition sources will not develop will depend upon the specific design features of the fuel tank system being evaluated. Detailed quantitative analysis should not be necessary if a qualitative safety assessment shows that features incorporated into the fuel tank system design protect against the development of ignition sources within the fuel tank system. For example, if all wiring entering the fuel tanks and their associated line replaceable units were shown to have protective features such as separation (including circuit separation in the LRU) and shielding and/or transient suppression/energy limiting devices, the portion of the compliance demonstration for the associated wiring would be limited to demonstrating the effectiveness of the features and defining any long-term maintenance requirements or critical design configuration control limitations so that the protective features are not degraded.

(2) Another example would be installation of a flame arrestor in the inlet line to a fuel pump. The compliance demonstration for the fuel pump may be limited to showing that the arrestor was effective at precluding propagation of the flame from the pump back down the inlet line into the tank, and showing that any anticipated failures or events could not violate the explosion-proof features of the pump assembly. In addition, revalidation of the fuel system to other regulations (e.g., icing and reduced flow due to contamination) would be required if modifications were incorporated to the fuel feed system. It may also be possible to show that fuel pumps installed such that the fuel pump inlet remains covered whenever the fuel pump is operating throughout the airplane operating attitude envelope, including anticipated low fuel operations and ground conditions, would be a satisfactory method of meeting the fail-safe requirement. The SSA criteria, process, analysis methods, validation, and documentation should be consistent with the guidance material provided in AC 25.1309 utilizing the unique guidance specific to the fuel tank system as defined in this AC.



**Figure 1: Fuel Tank System Fail-Safe Feature Considerations**

c. Assumptions and Considerations for Fuel Tank System Analysis. The analysis should be conducted based upon the following assumptions:

(1) Fuel Tank Flammability. The analysis should assume that the environment inside the fuel tank is always flammable. The conditions required to ignite fuel vapors from ignition sources vary with pressures and temperatures within the fuel tank and can be affected by sloshing or spraying of fuel in the tank. Due to the difficulty in predicting fuel tank flammability, the FAA has always assumed that a flammable fuel air mixture exists in airplane fuel tanks and has required that no ignition sources be present. The system safety analysis should be prepared considering all airplane in-flight, ground, service, and maintenance conditions, assuming that an explosive fuel air mixture is present in the vapor space of fuel tanks at all times, unless the fuel tank has features that mitigate the effects of tank ignition (e.g., polyurethane foam).

(2) Intrinsically Safe. Failures that create energy levels inside fuel tanks above intrinsically safe levels are considered to be an ignition source.

(3) Failure Condition Classification. Unless design features are incorporated that mitigate the hazards resulting from a fuel tank ignition event (e.g. polyurethane foam, adequate structural margin), the SSA should assume that the presence of an ignition source is a catastrophic failure condition.

(4) Latent Failures.

(a) In order to eliminate any ambiguity as to the restrictions on latent failures, § 25.981(a)(3) explicitly requires that any anticipated latent failure condition not leave the airplane one failure away from a catastrophic fuel tank ignition. In addition to this § 25.981(a)(3) limitation on latency, § 25.1309(c) limits latent failure conditions to those that do not create an “unsafe system operating condition.” Consequently, if a latent failure condition is not extremely remote (i.e., it is anticipated to occur) and it creates an “unsafe system operating condition,” then “warning information must be provided to alert the crew” and “to enable them to take appropriate corrective action.” These applicable regulatory restrictions on latency notwithstanding, there are practical limitations on the available means of compliance. For example, detecting a failure condition requires a finite period of time and there are not always “appropriate corrective actions” that can be taken during the flight. Consequently, for the purposes of compliance with § 25.981(a)(3), the period of latency for any anticipated significant latent failure condition should be minimized and not allowed to exceed one flight cycle. For the purposes of § 25.1309(c) compliance, any time the airplane is operating one failure away from a catastrophic fuel tank ignition should be considered an “unsafe system operating condition,” recognizing that sometimes the only “appropriate corrective action” is to continue on to your destination but not to initiate another flight without making appropriate repairs.

(b) Another practical limitation on the available means of compliance is the technological feasibility of providing inherent failure detection within the design for all significant failures. Sometimes periodic inspection is the only practicable means of reliably detecting a failure condition. Consequently, when such inspections are used as the means of detection, the inspection method and frequency must be sufficient to conclude that the occurrence of the significant latent failure condition is extremely remote. If the effectiveness of the inspection method is judged susceptible to human error, the procedure should be made a required inspection item (RII). (See 14 CFR 121.369(b) for considerations of a "required inspection item.")

(5) Failure Conditions. When showing compliance with § 25.981(a)(3), the effects of manufacturing variability, aging, wear, corrosion, and likely damage must be considered. For the purpose of compliance with § 25.981, “extremely remote” failure conditions are those not anticipated to occur to each airplane during its total life, but which may occur a few times when considering the total operational life of all airplanes of one type. This definition is consistent with that developed by the Aviation Rulemaking Advisory Committee (ARAC) for a revision to FAA AC 25.1309-1A, and that currently used by the Joint Aviation Authorities (JAA) in ACJ 25.1309. “Extremely improbable” failure conditions are those so unlikely that they are not anticipated to occur during the entire operational life of all airplanes of one type. This definition

is consistent with the definition provided in FAA AC 25.1309-1A and retained in the draft revision to AC 25.1309-1A proposed by the ARAC.

(a) The analysis should be conducted considering the deficiencies and anomalies listed in paragraph 6(g) of this AC, failure modes identified by the review of service information (including review of supplier service data), and any other failure modes identified by the functional hazard assessment of the fuel tank system. For example, the presence of conductive debris such as lockwire, steel wool, nuts, bolts, rivets etc., should be assumed. Section 25.981 specifically requires that the effects of manufacturing variability, aging, wear, corrosion, and likely damage must be considered when demonstrating compliance.

(b) The level of manufacturing variability, aging, wear, corrosion, and likely damage that must be considered should be determined based upon evaluation of the detectability of degraded or out-of-specification configurations, and established and documented within the analysis. In-service and production functional tests, component acceptance tests, and maintenance checks may be used to substantiate the degree to which these states must be considered. For example, inspection of fuel tank system bonding on production airplanes has shown that some bonds were inadequate. Functional testing of all bonding was incorporated to address this deficiency. In some cases (e.g., component bonding or ground paths), a degraded state will not be detectable without periodic functional test of the feature. For these features, inspection/test intervals should be established based on previous service experience on equipment installed in the same environment. If previous experience on similar or identical components is not available, conservative initial inspection/test intervals should be established until design maturity can be assured.

(6) External Environment. The severity of the external environmental conditions that should be considered when demonstrating compliance with § 25.981 are those established by certification regulations and special conditions (e.g., HIRF, lightning), regardless of the associated probability of exposure to any external environment. For example, the probability of lightning encounter should be assumed to be one.

(7) External Sources of Tank Auto-ignition. The possibility of fuel tank ignition due to auto-ignition sources created by external tank heating should be considered. This includes heating of the tank due to operation or failure of systems outside the tank within both the pressurized and unpressurized areas of the airplane, such as overloaded electric motors or transformers, failures in the pneumatic system and/or ducting that could cause localized heating of tank surfaces. In addition, the possibility of localized heating due to external fires must be considered. Section 25.967(e) requires that, "Each fuel tank must be isolated from personnel compartments by a fume proof and fuel proof enclosure." Leakage of fuel or vapor into spaces adjacent to the fuel tank, where a secondary fuel and fume proof barrier is not provided, has typically been assumed for areas such as:

- the wing leading and trailing edges,
- fairings located below the fuel tanks,

- fuel pump enclosures, and
- unpressurized areas of the fuselage surrounding fuel tanks located in the empennage.

Components located in these areas have been required to meet explosion proof requirements. These components or systems must be included in the analysis. Examples of equipment include, but are not limited to, ECS packs, motors, power assisted valves, fuel pumps, hydraulic pumps/motors, certain flight control actuators, ECS controls, and valves.

(8) Electrical Ignition Sources. The applicant should perform a failure analysis of all fuel systems and sub systems with wiring routed into fuel tanks. Systems that should be considered include fuel pump power and control and indication, fuel quantity indication, fuel temperature indication, fuel level sensors, and any other wiring routed into or adjacent to fuel tanks. The analysis should consider system level failures, failures within line replaceable units (LRU) and component level failures discussed below. The analysis should include existence of latent failures and subsequent failures that may lead to an ignition source within the fuel tank. Examples include undetected failures of tank components or wiring, the undetected presence of conductive debris, damage to FQIS or level sensor probes, or corrosion (copper or silver sulfur), in combination with external failures such as hot shorts or induced transients (EMI and lightning). In addition, the applicant should provide a description of the protective means employed in the fuel system wiring. This should include a description of features such as separation/segregation, transient suppression devices, and shielding of wiring and methods employed to maintain configuration control of critical wiring throughout the life of the airplane.

**NOTE:** EMI protection is often a function of circuit and surrounding structural characteristics. Therefore care should be taken when determining the effects of exposing a system with faults present to some EMI threat, especially lightning.

(9) Electrical Short-Circuits.

(a) Incorporation of protective features that mitigate the effects of electrical short-circuits that could occur outside the fuel tanks, such as separation of fuel tank wires and circuits from electrical power wires and circuits, combined with shielding between wiring that enters fuel tanks and any electrical power-carrying wires in the aircraft installation, has been used on certain airplane types to provide a fail-safe design with respect to electrical shorts. The effects of electrical short circuits, including hot shorts, on equipment and wiring that enters the fuel tanks should be considered, particularly for the fuel quantity indicating system wiring, fuel level sensors, and probes. Latent failures from factors such as contamination, damage/pinching of wires during installation, or corrosion on the probes, connectors, or wiring should be considered when evaluating the effects of short circuits. The wire routing, shielding, and segregation outside the fuel tanks, including within the FQIS components (e.g., gaging units), should also be considered when evaluating the effects of short circuits. The evaluation should consider both electrical arcing and localized heating that may result from short circuits on equipment, fuel quantity indicating system probes, and wiring. The evaluation of electrical short circuits should include consideration of shorts within electrical equipment, and wiring from the equipment into

the fuel tank. Prevention of fuel ignition from electrical shorts to wiring that enters fuel tanks may require specific wire and circuit separation and wire bundle shielding.

(b) Another method that has been proposed to provide protection of circuits that enter fuel tanks from electrical short circuits is the installation of a transient suppression device on the circuit close to the point where those wires enter fuel tanks

(10) Line Replacement Unit (LRU) Design Evaluation. Line replaceable units include any components that can be replaced while the airplane remains in operational service. Examples of fuel system LRU's include components such as cockpit and refueling panel fuel quantity indicators, fuel quantity system processors, and fuel system management control units. The design review should include evaluation of the separation and/or protective features incorporated into any fuel system LRU whose failure could result in high level electrical power entering the fuel tank. Any LRU that meets the design requirements identified in reference (3), paragraph 4f, of this AC, Underwriters Laboratories Inc., UL 913, Intrinsically Safe Apparatus and Associated Apparatus for use in Class I, II, III, Division 1, Hazardous (Classified) Locations, would provide adequate separation of the power sources within the LRU.

(11) Electromagnetic Effects, including Lightning, Electromagnetic Interference (EMI), and High-Intensity Radiated Fields (HIRF).

(a) The effects of electrical transients from lightning, EMI, or HIRF on anything conductive (e.g. fuel tank plumbing, structure, fuel, equipment and wiring) within the fuel tanks should be considered, particularly for the fuel quantity indicating system wiring and probes. Latent failures from factors such as contamination, damage, or corrosion on the probes or wiring should be considered when evaluating the effects of electrical transients. The wire routing, shielding, and segregation of conductors (e.g. plumbing, component casings, wiring, etc.) outside the fuel tanks should also be considered when evaluating the effects of electrical transients, because the transient generation and coupling to conductors may occur outside the fuel tanks. The evaluation should consider both electrical arcing and localized heating that may result from lightning, EMI, and HIRF transients on the fuel tank system, fuel quantity indicating system probes, and wiring.

(b) Latent failure of electromagnetic protection features, such as shielding termination corrosion, shield damage, and transient limiting device failure should be considered and appropriate indication or inspection intervals established to prevent the existence of latent failure conditions. The failure of other system components may also affect EMI protection. Consequently, the effect of any anticipated failure on the continued environmental protection should be considered. For example, a normally high impedance electrical load that fails due to an electrical short, or a normally low impedance load that fails to an open state, can cause a significant redistribution of the lightning currents within a wire bundle; hence, the voltage induced at components within the fuel tank.

(c) The evaluation of electromagnetic effects from lightning, EMI, or HIRF should be based on the specific electromagnetic environment of a particular aircraft model.

Standardized tests, such as those in RTCA DO-160, Sections 19, 20, and 22, are not sufficient alone, without evaluation of the characteristics of the specific electromagnetic environment for a particular aircraft model, to show that appropriate standardized DO-160 test procedures and test levels are selected. Simulation of various latent failures of fuel system components within the tanks may be required to demonstrate the transient protection effectiveness.

(d) Prevention of fuel ignition due to electrical transients from lightning, EMI, or HIRF may require specific wire segregation and separation, wire bundle shielding, or transient suppression for wires entering fuel tanks. Effectiveness of the transient protection features should be verified using the appropriate DO-160 test procedures and test levels determined above.

(12) Friction Sparks. The failure modes and effects analysis (FMEA) should include evaluation of the effects of debris entering the fuel pumps, including any debris that could be generated internally, such as any components upstream of the pump inlet. Industry fuel tank cleanliness practices and design features intended to preclude debris entering the fuel pumps have not been effective at eliminating debris. Service experience has shown that pump inlet check valves, inducers, nuts, bolts, rivets, fasteners, sealant, lockwire, etc. have been inducted into fuel pumps and contacted the impeller. This condition could result in creation of friction sparks and should be an assumed failure condition when conducting the system safety assessment. Fail-safe features should be incorporated into the fuel pump design to address this condition. Examples of means that may be incorporated into the fuel pump design to address this concern include:

- Installation of inlet flame arrestors,
- Use of reticulated foam,
- Use/installation of jet fuel pumps without impellers to scavenge fuel, or
- Maintaining fuel over the pump inlet throughout the airplane flight attitude envelope.

## 10. COMPONENT QUALIFICATION CONSIDERATIONS.

a. Component Qualification Review. Qualification of components, such as fuel pumps, using the MIL specifications has not always accounted for unforeseen failures, wear, or inappropriate overhaul or maintenance. Service experience indicates that explosion proof capabilities should be substantiated (or re-substantiated for the SFAR compliance) considering these factors in addition to those conditions noted in paragraph 6g of this AC. Therefore, an extensive evaluation of the qualification of components may be required if qualitative assessment does not limit the component as a potential ignition source.

b. Determining Maximum Component Temperature. Maximum component temperatures may be determined experimentally. Tests should be conducted long enough for the component to reach the maximum temperature. All foreseeable failures and malfunctions of the fuel tank components (including those failures and malfunctions that could be undetected by the flightcrew and maintenance personnel) should be considered when determining maximum temperatures and

possible development of electrical arcing or sparking in the fuel tank. The following list, although it does not include all possible failure modes, suggests some conditions that should be explored as applicable:

- Normal operation
- Single phase operation of three-phase electrical components. In many cases fuel pump motors are protected by a (single) three-phase circuit breaker. In several instances, resetting of circuit breakers has resulted in arcing inside the fuel tank and the development of an ignition source. Therefore, the fuel pump circuit should also preclude development of an ignition source if the breaker is reset or forced in by a mechanic. Features such as non-resettable breakers or fuses are design features that would meet the fail-safe requirements of § 25.901 that apply to this failure condition.
- Two-phase operation of three-phase electrical components. Failure of a single phase of a multiple-phase fuel pump may significantly increase the load on the remaining phases of the pump and generation of heat in the pump. In many cases thermal protection features within the pump have been incorporated to address this failure condition. Another failure condition that should be considered is subsequent failure of a second phase of the pump and possible arcing or heat damage. In general, pumps should not be allowed to operate following failure of a single electrical phase of the pump if such operation could result in development of an ignition source. Automatic protective means, such as arc/ground fault interrupters, should be provided to shut down the pump when a single electrical phase failure occurs. Periodic inspections or maintenance of these features may be required.
- Dry operation of mechanical components including lack of lubrication. Service history has shown that flightcrews and maintenance personnel have inadvertently operated fuel pumps for long periods of time without fuel in the fuel tank. Fuel pumps are typically qualified for dry run operation for differing periods of time. For example, some pumps were qualified with up to a maximum of 8 hours continuous, with total accumulated dry run operation of 24 hours. Indefinite operation of pumps may result in surface temperatures above the autoignition temperature. Manufacturers recommended procedures are not adequate to assure that pumps will not inadvertently be operated for long periods of time without fuel in the tank. Therefore, if indefinite operation in an empty fuel tank can result in a surface temperature that is an ignition source in the fuel tank, additional fail-safe features are necessary to preclude dry run operation of airplane fuel pumps beyond the time for which the pump was originally qualified. One or more of the following fail-safe means should be considered for protection of fuel pumps:

- Qualified for indefinite dry run operation.
- Incorporation of automatic pump shutoff features into the fuel pump or airplane to preclude dry run operation past the dry run qualification demonstration time.
- Annunciation of dry run operation of the pump and FAA approved Airplane Flight Manual procedures that require shutoff of the pump.
- Other means such as installation of flame arrestors to preclude flame propagation into the fuel tank.

**NOTE:** Annunciation of inadvertent pump operation should be in accordance with the annunciation requirements of § 25.1309. For airplanes configured with a two-crew flight deck, cautionary level annunciation would be appropriate.

- Wet operation of mechanical components with zero and reduced fluid flow
- Moving mechanisms locked or seized
- Pump impeller slippage
- Failed Bearings. The effects of wear on fuel pump features incorporated into the design to maintain explosion proof characteristics should be evaluated. For example, wear of bearings or failures, including spinning of any bushings, and possible effects on quenching orifices should be evaluated. In many cases fuel pump explosion proof features are not redundant and failure or degradation of the features is latent. If single or probable combinations of failures in the fuel pump can cause an ignition source, § 25.981 requires incorporation of fail-safe features noted previously. If wear of the pump can cause degradation of fail-safe features, appropriate inspection, overhaul or life limiting of the pump should be included in the Limitations section of the Instructions for Continued Airworthiness.
- Failed or Aged seals. Spraying of fuel in the tank from any pressurized fuel source may cause electrostatic charging of components in the fuel tank and significantly increase the range of temperature during which the fuel tank vapors are flammable. The design should not include features that result in spraying of fuel, such as fuel pump motor cooling flow return to the tank. In addition, use of sealant in connectors that is not compatible with fuel may allow leakage into the connector and the possibility of a fire near the connector.

Fuel Line Couplings. Aging of seals may result in hardening of the seal material and leakage and spraying of fuel within the fuel tank; therefore, fuel line coupling

designs should be evaluated and a design life should be established for all seals that are shown to age and allow leakage.

Fuel Pump Cooling Flow. Fuel used for cooling of fuel pumps may be sprayed from the fuel pump. Fuel pump cooling flow should not be sprayed into the fuel tank vapor space. Means should be provided to distribute the cooling fuel into the fuel tank at or near the bottom of the fuel tank.

Electrical Connector Sealant, Seals, and Explosion Proofness. Electrical connections to fuel pumps are typically located either inside or outside the fuel tank in areas of the airplane where the presence of flammable fuel vapors should be assumed because no secondary sealing of fuel is provided. Fuel leakage and corrosion at electrical connectors located outside the fuel tank has allowed the presence of both flammable vapors and electrical arcing at connectors, resulting in fires. In other applications, arcing has occurred at the pump connections inside the fuel tanks, requiring installation of appropriately sized steel shields to prevent arcing through the connector or pump housing into the fuel tank or areas where flammable vapor could exist.

Arcing at the pump electrical connections should be assumed with fuel present in the safety assessment. The energy release during an arcing condition may be limited by installation of arc/ground fault protection features. The pump connector should be shown to contain any resultant arcing or fire and maintain all surface temperatures below the auto-ignition temperature of the fuel. Component manufacturer maintenance records and qualification test results should be reviewed to establish that the sealant is compatible with the fuel and to determine if a design life or periodic inspections for the pump connector are needed.

- Electrical defects that generate excessive heat. Arcing at the electrical connections to the pump housing or within the connector.
- Submerged heat exchangers. Operating under conditions of maximum heat rejection to the fuel.

c. Determination of Maximum Temperature of Fuel Tank Surface.

(1) Components mounted adjacent to the exterior surface of the fuel tank can create a high localized temperature at the inner surface of the tank. This can be investigated by laboratory tests that duplicate the installation, or by a validated heat transfer analysis using the maximum potential temperature of the component.

(2) External Heat Source. When engine bleed air ducting, Environmental Control Equipment (ECS), and other airplane components or systems are located near fuel tanks, an FMEA should be made to determine failures of adjacent systems or components that could cause elevated surface temperatures. The maximum internal tank temperatures that can occur during

normal and failure conditions should be determined. Systems, such as over-temperature protective devices, should be evaluated to determine if periodic health checks are necessary to assure that latent failures do not exist.

#### 11. INSTRUCTIONS FOR CONTINUED AIRWORTHINESS OF THE FUEL TANK SYSTEM--§ 25.1529.

a. Based upon the evaluations required by § 25.981(a), Amdt. 25-102, also added a new requirement to § 25.981(b) to require that critical design configuration control limitations, inspections, or other procedures be established, as necessary, to prevent development of ignition sources within the fuel tank system, and that they be included in the Airworthiness Limitations section of the Instructions for Continued Airworthiness (ICA) required by § 25.1529. This requirement is similar to that contained in § 25.571 for airplane structure. Amendment 25-102 also added a new requirement to Appendix H to part 25, Instructions for Continued Airworthiness (ICA), to provide any mandatory fuel tank system inspections or maintenance actions in the limitations section of the ICA.

b. Critical design configuration control limitations include any information necessary to maintain those design features that have been determined by analysis of the fuel tank system as needed to preclude development of ignition sources. They may include any maintenance procedure that could result in a failure, malfunction, or defect endangering the safe operation of the airplane, if not performed properly or if improper parts or materials are used. This information is essential to ensure that maintenance, repairs, or alterations do not unintentionally violate the integrity of the original type design of the fuel tank system.

c. Any fuel tank system components that are determined to require periodic maintenance, inspection, or overhaul to maintain the integrity of the system or maintain protective features incorporated to preclude a catastrophic fuel tank ignition event must be defined and included in the Limitations section of the Instructions for Continued Airworthiness. The inspection interval should be established based upon the standard practices defined in AC 25.1309 for evaluation of component failures. Examples of such items include:

(1) Aging fuel line couplings seals/ o-rings. In certain instances, materials used in fuel line couplings may lose flexibility and harden with age. During suction feed or pressurized operation, the seal may allow air to enter the fuel line or leak, allowing spraying of fuel in the tanks or other areas of the airplane where spraying fuel could create a fire hazard. Repetitive inspections, functional checks, or mandatory replacement intervals may be required to prevent leakage.

(2) Wear of pump bushings, bearings, and seals may significantly affect the performance of fuel pumps and degradation of features necessary to maintain the explosive proof qualification. In most cases these failures conditions are latent, therefore incorporation of other fail-safe features, as discussed earlier in this AC, would be required. If fail-safe features are incorporated, such as installation of feeder tanks that are filled with ejector pumps, functioning of the ejector pumps would need to be assured by indications or periodic functional tests.

Installation of flow indicators in the motive flow line of the pump that can be viewed by maintenance personnel and a mandatory inspection of this function is one example of a method of mandatory maintenance action.

(3) Fuel pump protective features. If failure of an arc/ground fault protective feature and/or a thermal fuse (closed) is latent and this feature is needed to maintain fail-safe features, periodic checks may be needed.

(4) Transient suppression/energy limiting devices. If failure of the device is latent and this feature is needed to maintain fail-safe features, periodic checks will be needed.

(5) Wire shield grounding.

(6) Component grounds and wires will likely require inspections and measurements to determine proper grounding.

(7) Fuel tank access panel/door seals leakage, resistance checks.

(8) Fuel pump connectors, corrosion, wear.

(9) Fuel pump electrical supply conduit structural, sealing integrity.

d. Maintainability, both in the design and procedures (i.e., MMEL, Airplane Maintenance Manual, etc.), must be verified. This should include, as a minimum, verification that the system and procedures support the safety analysis assumptions and are tolerant to anticipated human errors, and that any critical procedures are highlighted for consideration as required inspection items. (See 14 CFR 121.369(b) for considerations of a "required inspection item.")

e. Visible Identification of Critical Design Configuration Limitations.

(1) Section 25.981(b) states that "...visible means must be placed in areas of the airplane where maintenance, repairs, or alterations may violate the critical design configuration limitations." The design approval holder should define a method of ensuring that this essential information will be communicated by statements in appropriate manuals, such as Wiring Diagram Manuals, and be evident to those that may perform and approve such repairs and alterations.

(2) An example of a critical design configuration control limitation that would result in a requirement for visible means would be maintaining wire separation between FQIS wiring and other high power electrical circuits where separation of the wiring was determined to be a critical design configuration control limitation. Acceptable means of providing visible means would

include color coding of the wiring or, for retrofit, placement of identification tabs at specific intervals along the wiring.

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